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Evaluation of the Effects of the ZetaLiner During Helmet Impact

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November 1999

Interim Report for the Period August 1999 to November 1999

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

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FOR THE DIRECTOR

Roger L. Stork

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An experimental effort was conducted to compare the ZetaLiner, a new foam flight helmet liner manufactured by Oregon Aero, to the Thermal Plastic Liner (TPL), the helmet liner used in the USAF's standard flight helmet, the HGU-55/P. The liners were compared based on their effectiveness in attenuating impact acceleration and minimizing head injury potential. A series of vertical drops with a Helmet Drop Tower (HDT) were conducted using HGU-55/P flight helmets, TPLs, and several ZetaLiner samples. In addition to the liner comparison, helmet impacts were also conducted to evaluate Oregon Aero's Ballistic Liner Upgrade (BLU) compared to the rigid foam liner used in the HGU-55/P. All tests exposed the helmet shell to impacts against a hemispherical anvil as outlined in military standard MIL-H-87174. The probability of head injury, as defined by the Head Injury Criteria (HIC), was calculated using measured impact acceleration of the HDT headform for each helmet configuration. Test results indicated that all impact configurations passed the acceleration standard as outlined in MIL-H-87174. The headform acceleration, resulting HIC values, and probability of severe brain injury values for the ZetaLiner tests were less than the comparative values for either the standard ACES II TPL or the HGU-55/P helmet with the BLU.

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PREFACE

An experimental effort was conducted to compare the ZetaLiner, a new foam flight helmet liner manufactured by Oregon Aero, to the Thermal Plastic Liner (TPL), the helmet liner used in the USAF's standard flight helmet, the HGU-55/P. The helmet liners were compared based on their effectiveness in attenuating impact acceleration and minimizing head injury potential. A series of vertical drops with a Helmet Drop Tower (HDT) and an instrumented headform were conducted using HGU-55/P flight helmets, TPLs, and several ZetaLiner samples. In addition to the liner comparison, helmet impacts were also conducted to evaluate Oregon Aero's Ballistic Liner Upgrade (BLU) compared to the rigid foam liner used in the HGU-55/P. The probability of head injury, as defined by the Head Injury Criteria (HIC), was calculated using measured impact acceleration of the HDT headform for each helmet configuration. The helmet impact tests and data analysis described in this report were accomplished by the Biodynamics and Acceleration Branch, Biodynamics and Protection Division, Human Effectiveness Directorate of the Air Force Research Laboratory (AFRL/HEPA) at Wright-Patterson Air Force Base OH. The tests were conducted at the request of Mr. John Hopkins at HSW/YACL, Brooks Air Force Base TX. Test facility and engineering support at AFRL/HEPA were provided by DynCorp, Inc. under contract F33601-96-DJ001.

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INTRODUCTION

To ensure safety and protection for Air Force and DoD pilots, changes to the helmet shell or interior soft or hard liners may necessitate additional testing of the helmet for compliance with its design requirements. The USAF Human Systems Program Office (HSW/YA) has proposed to use a new foam flight-helmet liner in place of the standard soft liner or Thermal Plastic Liner (TPL) currently used in the USAF HGU-55/P flight helmet. The new foam liner, termed the ZetaLiner, is manufactured by Oregon Aero, Inc., and is an energy absorbing liner composed of a rate-dependent foam which conforms to the surface contours of the head. The proposal to upgrade the HGU-55/P's TPL liner with the new ZetaLiner required that the helmet be re-evaluated to ensure the energy absorption properties of the current HGU-55/P flight helmet had not been compromised.

Tests were also conducted with the HGU-55/P helmet fitted with an upgrade to the helmet's rigid foam liner and with an upgrade to the helmet's standard hard-shell earcup. The rigid foam liner upgrade, termed the Ballistic Liner Upgrade (BLU), is also manufactured by Oregon Aero, and replaced the rigid foam liner in the standard helmet shell. The earcup upgrade, termed the Combo Earcup, is also manufactured by Oregon Aero, and replaced the standard foam and hard shell earcups. The additional tests were used to compare the impact attenuation performance of the BLU against the standard rigid foam liner and TPL combination, and to compare the impact attenuation performance of the Combo Earcups against the standard earcups during helmet shell impacts at locations on the shell dimple located over the earcup position.

The evaluation of the proposed upgrades was accomplished by conducting impact attenuation tests on the HGU-55/P with the TPL liner as a baseline, and then on various rigid foam, soft liner, and earcup configurations. The tests were conducted as outlined in Section 4 of Military Standard MIL-H-87174. A series of vertical drop tests using a vertical-drop helmet impact facility exposed an HGU-55/P helmet with either of the two different soft liners to impacts against a hemispherical impact anvil as outlined in the military standard. Acceleration data, which were collected by an instrumented headform, were compared to criteria also detailed in

the standard. Head injury risk for each configuration was also evaluated using the Head Injury Criteria or HIC.

BACKGROUND

The ANSI Z-90 Standard is a broad-based set of specifications for general protective headgear to minimize head injury. The standard describes a series of tests designed to evaluate the impact attenuation capabilities and the penetration resistance of a helmet. The purpose of the impact tests is to limit the acceleration imparted to the head, and the purpose of the penetration resistance tests is to limit the protrusion of a sharp object through the helmet and into the head.

Military flight helmets were designed with specific features to provide aircrew protection [1,4]. A variation of the ANSI Z-90 Standard is often used to evaluate aviator helmets. One such variation is Military Standard MIL-H-87174, which was used to evaluate and procure the HGU-55/P helmet. In addition to the ANSI Z-90 standard, other procedures and methodologies to measure the effectiveness of the proposed head protection have also been developed.

Specific tolerance criteria for head injury have been proposed by various research groups, and most are described in Stapp Car Crash Conference proceedings [2,3,10,11]. The Wayne State Tolerance (WST) curve was one of the first established tolerance criteria, and was then followed by a weighted-impulse integration procedure developed by Charles Gadd [2]. This became known as the Gadd Severity Index (GSI). A modified version of the GSI, using a maximization technique for the integration procedure, was adopted by the National Highway Traffic Safety Administration (NHTSA) of the Department of Transportation (DOT), and was called the Head Injury Criterion (HIC) [5]. These criteria and others were based on measured skull accelerations with the assumed injury being brain injury (severe concussion) or a combination of skull fracture and brain injury. For example, a HIC value of 1000 corresponds to a probability of a severe (Abbreviated Injury Scale (AIS) rating greater than 4) brain injury of approximately 16% [6].

METHODOLOGY

The critical issues for the ZetaLiner impact test program were to evaluate the ZetaLiner as indicated in Military Standard MIL-H-87174 and compare it to the standard TPL liner; determine the effectiveness of the ZetaLiner in reducing head injury potential as compared to the standard TPL liner using the 15 ms HIC (HIC calculation limited to a maximum 15 ms pulse width); and determine the effects of the BLU on measured headform acceleration and head injury potential as compared to the standard rigid foam liner, using MIL-H-87174 and a15 ms HIC.

A series of vertical drops using 35 ft-lb of impact energy were conducted with the HGU-55/P flight helmet mounted on a headform to evaluate impact attenuation. The vertical drop tests were conducted using the AFRL/HEPA Helmet Drop Tower (HDT) facility [7,8,9]. The HDT facility is composed of two steel cables that act as guides for a low resonant magnesium alloy headform mounted to a vertical displacement carriage. After affixing a helmet to the HDT headform, the carriage was raised to a specific height and then allowed to free-fall onto a rigid impact surface. The impact surface was a standard hemispherical impact anvil of approximately 1.9 inch radius. The anvil was rigidly mounted to a load cell that measured the force of the impact. A 300 lb stationary base (reaction mass) supported the load cell. The headform could swivel on a pivot arm and then be locked into position, allowing impacts at any point on the surface of the helmet. The impact energy was controlled by the initial height of the carriage prior to free-fall. The facility is shown in Figure 1 with a standard USAF flight helmet.

The test program consisted of impact tests outlined in paragraph 4.6.8 of MIL-H-87174. The standard called for impacts at 5 different locations on the helmet shell, using the hemispherical anvil to evaluate impact attenuation. The helmet was dropped from the correct height to produce 35 foot-pounds of impact energy. The helmet was subjected to *single* impacts at the front, back, crown (apex), and each side. The site of each impact was just above the "Reference Plane" line identified on the magnesium headform used for each test shown in Figure 2.

The following impact configurations were evaluated by impact at the five locations identified in MIL-H-87174: (1) HGU-55/P flight helmet with 5-layer standard TPL; (2) HGU-55/P with size 15-5 ZetaLiner; (3) HGU-55/P flight helmet with BLU and ZetaLiner; and (4) HGU-55/P flight

helmet and ZetaLiner with Combo Earcup. In addition, impacts were conducted on the left side of the helmet at the site of the dimple on the outer shell, which is approximately at the center of the earcup. A test matrix is shown in Table 1.

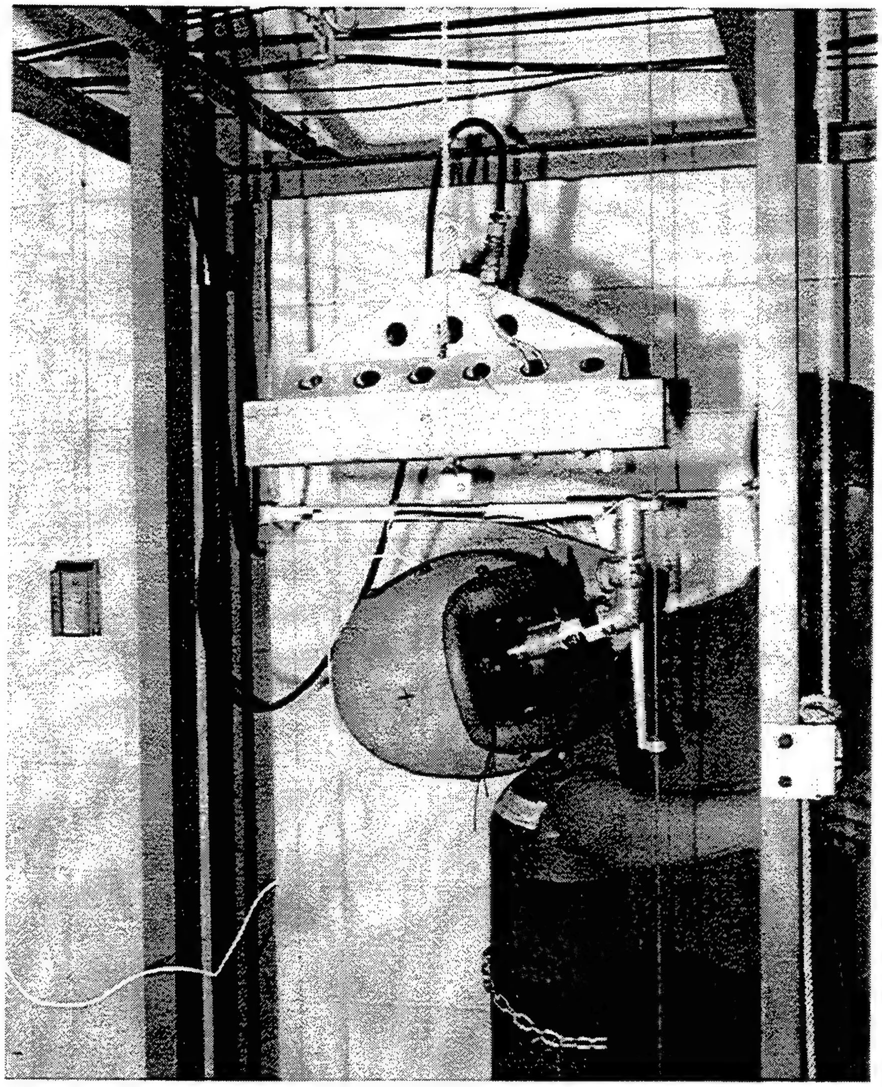

Figure 1. AFRL/HEPA Helmet Drop Tower

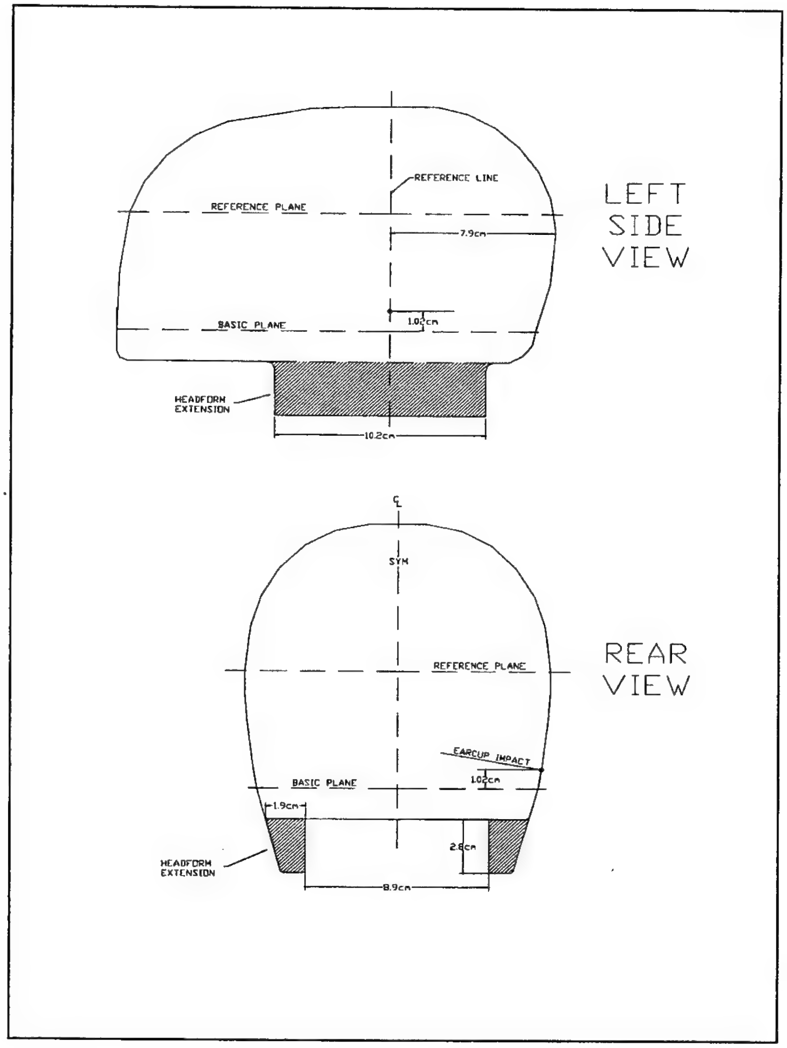

Figure 2. Sketch of Modified Headform Used with Helmet Drop Tower

Table 1. ZetaLiner Evaluation Test Matrix

Impact Location	Standard TPL Liner	ZetaLiner	Ballistic Liner Upgrade	ZetaLiner + Combo Earcup	Standard Earcup (Dimple)	Combo Earcup (Dimple)
Helmet Top	A1	B1	C1			
Helmet Back	A2	B2	C2			
Helmet Front	A3	B3	C3			
Right Side	A4	B4	C4	D4		
Left Side	A5	B5	C5	D5	E5	F5

The TPL liner was covered with the standard black cloth cover. The ZetaLiner is composed of Confor rate-dependent foam, and was also covered with a black cloth cover. The size 15-5 ZetaLiner corresponds to the same approximate thickness as a 5-layer TPL liner. The BLU upgrade was used in conjunction with a ZetaLiner, and replaced the standard hard foam liner in the HGU-55/P helmet. The BLU consisted of a series of 9 individual or separate Confor foam pads with different mechanical properties from the ZetaLiner Confor foam, and was covered in a black cloth cover. Each of the 9 pads was placed in a specific location inside the shell after removal of the hard foam liner. These configurations are shown in Figures 3, 4, and 5.

The tests of the ZetaLiner with the Combo Earcup (Cells D4 and D5) were conducted identically to the tests at the same impact location in Cells B4 and B5, except the Combo Earcup, composed of rate-dependent foam, was used in place of the standard HGU-55/P helmet foam earcups. These tests were repeated again in Cells E5 and F5 on the left side of the helmet, but the impact was directly on the shell dimple located over the center of the earcup, providing a better source of data to evaluate the protective properties of the Combo Earcup. These tests were conducted because the tests in Cells B4, B5, D4, and D5 had the impacts applied at a location on the shell

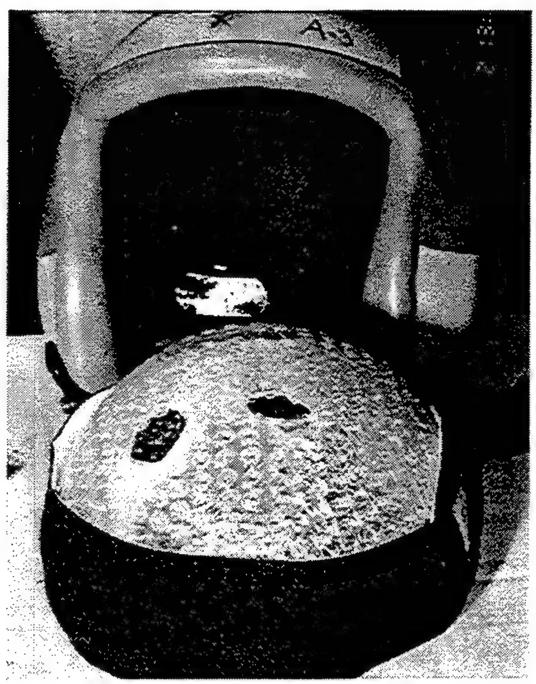

Figure 3. TPL Shown with HGU-55/P Helmet

Figure 4. ZetaLiner Shown with HGU-55/P Helmet

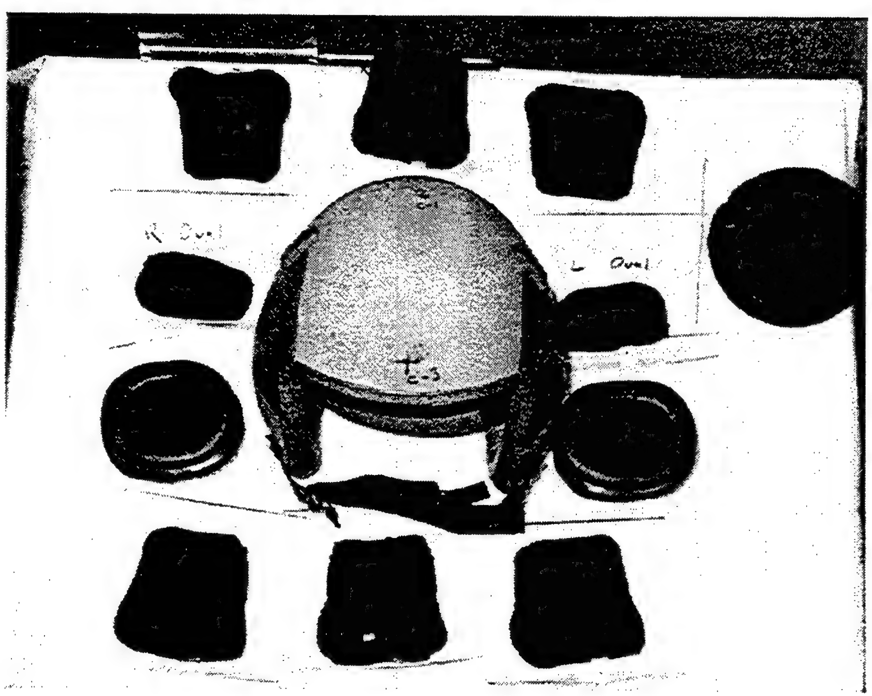

Figure 5. Ballistic Liner Upgrade Kit Shown with HGU-55/P Helmet

that approximated the top of the earcup region, and therefore did not effectively evaluate the Combo Earcup.

According to MIL-H-87174, the helmet failed the impact evaluation at any of the five impact sites if: (1) the acceleration of the headform exceeded 400 G for any time; (2) the acceleration of the headform exceeded 200 G for a minimum of 3 seconds; or (3) the acceleration of the headform exceeded 150 G for a minimum of 6 seconds. A series of pre-tests using the HGU-55/P helmet were conducted to calibrate the HDT to determine the correct drop height for the required impact energy since it is a function of drop height and HDT carriage weight. To calibrate the HDT facility (relate drop height input to impact energy output), a friction factor for the steel guide cables was calculated. To determine the friction factor, an initial theoretical drop height was calculated using the following equation:

$$h = E/w \qquad (1)$$

where h is the theoretical drop height, E is the required energy at impact, and w is the weight of the carriage, headform, and helmet.

Knowing the initial theoretical drop height, a theoretical free-fall time for the carriage and components was calculated using the following equation:

$$t_{TF} = ((2 * h)/a)^{0.5} \qquad (2)$$

where t_{TF} is the theoretical free-fall time, h is the theoretical drop height, and a is the acceleration due to gravity. Using a drop height of approximately 3 feet, equation 2 was solved to find a theoretical free-fall time of 0.432 second. Knowing the theoretical free-fall time, a series of four impacts were conducted at a drop height of h equal to 3.0 feet. The actual free-fall time was calculated for each test, and the average value of the four tests was used to calculate the cable friction factor using the following equation:

$$F_f = (t_{AF} - t_{TF})/t_{TF} \qquad (3)$$

where F_f is the cable friction factor, t_{AF} is the average actual free-fall time, and t_{TF} is as defined previously. The friction factor was found to be 0.085. This value was then used to calculate the drop height for each configuration with a specific total carriage weight, as determined by the test matrix. The drop height was calculated using the following equation:

$$D_h = (E / w) + (F_f * (E / w)) \qquad (4)$$

where D_h is the final drop height, E is the impact energy, w is the carriage assembly weight, and F_f is the cable friction factor. The carriage assembly was raised to the proper drop height for each test and released by an electronically-activated solenoid and allowed to free-fall.

Data acquisition for the series of tests consisted of the headform acceleration time history from the internally-mounted single-axis accelerometer, and the time history of the load imparted to the headform from the flat load cell mounted under the hemispherical impact anvil. All tests were visually documented using a Kodak high-speed video camera running at 500 frames per second. Test requirements consisted of analyzing the acceleration peaks and calculating the HIC value using the acceleration time history. The calculated HIC values represent given probabilities of severe (AIS ≥ 4) brain injury, which were then compared across test conditions. The HIC was calculated using Equation 5 where $(t_2\text{-}t_1)$ was varied up to a maximum of 15 ms. The relationship between HIC and the probability of brain injury is shown in Figure 6 [6]. As a point of reference, HIC values of 700 and 1000 correspond to probabilities of injury of approximately 4.5% and 16% respectively.

$$HIC = (A_{avg})^{2.5} * (t_2 - t_1) \qquad (5)$$

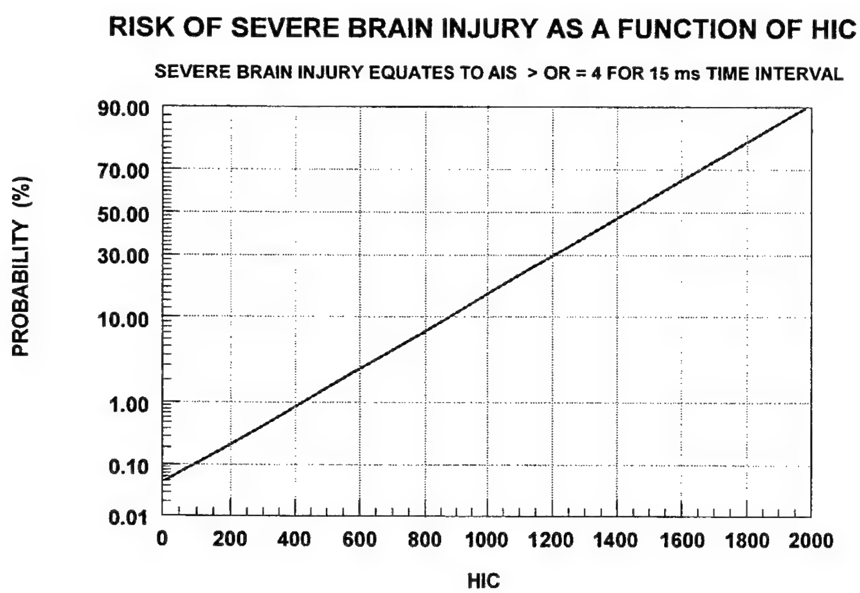

Figure 6. Risk of AIS ≥ 4 Brain Injury as a Function of 15 ms HIC

RESULTS AND DISCUSSION

One helmet impact was conducted at each of the five locations for three of the configurations with the TPL, the ZetaLiner, and the BLU (Cells A, B, and C). A limited number of impacts were conducted on the side of the helmet with the different earcup combinations (Cells D, E, and F). A summary of the peak acceleration data for the test configurations is shown in Table 2.

Table 2. Peak Headform Acceleration (G) Per Configuration

Impact Location	Standard TPL Liner	ZetaLiner	Ballistic Liner Upgrade	ZetaLiner + Combo Earcup	Standard Earcup (Dimple)	Combo Earcup (Dimple)
Top	50.59	50.69	47.09			
Back	68.58	57.54	86.31			
Front	130.67	92.57	124.79			
Right Side	83.26	74.29	91.90	80.76		
Left Side	93.66	73.31	102.71	75.97	95.60	67.31

In general, the impacts to the front of the helmet produced the highest acceleration peaks, while impact to the top produced the lowest acceleration peaks. The time to peak for the acceleration pulses ranged from 7 to 12 ms, and the total impact duration ranged from 12 to 30 ms. Impacts to the front of the helmet were typically 12 to 14 ms in duration, while impacts at the other locations ranged between 20 and 30 ms. Peak acceleration data analysis consisted of comparing the values to the MIL-H-87174 requirement, and comparing the values in each configuration to each other. It is theorized that the highest acceleration values are associated with the front impacts to the helmet shell because the shell stiffness is slightly greater at this point than at the other impact locations due to the shell's radius of curvature. The higher stiffness of the shell absorbs less of the impact energy, therefore transmitting it through the hard and soft shell liners to the headform.

The peak acceleration data indicate that all test configurations passed MIL-H-87174 since there were no acceleration peaks above 150 G. A summary of the configuration comparison analysis

is shown in Table 3. The table presents the percent increase (+ %) or percent decrease (- %) in the peak values between selected configurations. For example, when comparing data from the TPL and the ZetaLiner configurations during the frontal impact test, the ZetaLiner showed a 29.2% decrease in peak head acceleration. In general, the configuration comparison analysis indicated that the ZetaLiner decreased the head acceleration compared to the TPL liner in all impact locations except the top of the helmet, where it generated an equivalent peak acceleration. The BLU increased the head acceleration at the back, right-side, and left-side impact locations, but showed slight improvement (decrease in peak acceleration) at the top and the front impact locations. The use of the Combo Earcups did not significantly affect the head acceleration at the side impact locations as directed by MIL-H-87174. However, impacts to the side of the helmet at the location of the helmet shell dimple, using the standard and Combo Earcup, indicated that the Combo Earcup reduced the peak head acceleration by approximately 30%.

Table 3. Summary of Analysis of Peak Headform Accelerations

Impact Location	TPL vs ZetaLiner (+/-) % Change	TPL vs BLU Upgrade (+/-) % Change	Standard vs Combo Earcup (+/-) % Change	Standard vs Combo Earcup at Dimple (+/-) %Change
Top	**+0.012 %**	**-6.9 %**		
Back	**- 16.1 %**	**+25.85 %**		
Front	**- 29.2 %**	**-4.42 %**		
Right Side	**- 10.77 %**	**+10.4 %**	**+8.7 %**	
Left Side	**- 21.73 %**	**+ 9.66 %**	**+3.6 %**	**-29.6 %**

The acceleration time histories for each test were also processed to calculate the HIC value using a Fortran routine programmed with the HIC equation (Equation 5), and using a time interval ($t_2 - t_1$) up to 15 ms maximum. The HIC values for each test configuration were calculated and are reported in Table 4. Calculating the probability of brain injury for each test condition was the final analysis used to compare the different helmet liner and earcup configurations. Figure 3 was used to determine the probability of severe brain injury (AIS $\geq$ 4) as a function of the HIC values

shown in Table 4. The results are shown in Table 5. A bar graph is shown in Figure 7 to highlight the variation in probability of head injury as a function of the liner configurations and the impact locations.

Table 4. HIC Values per Configuration

Impact Location	Standard TPL Liner	ZetaLiner	Ballistic Liner Upgrade	ZetaLiner + Combo Earcup	Standard Earcup (Dimple)	Combo Earcup (Dimple)
Top	145	152	109			
Back	199	166	259			
Front	512	282	482			
Right Side	254	217	270	241		
Left Side	267	181	303	260	392	158

Table 5. % Probability of Head Injury Values (AIS>4) per Configuration

Impact Location	Standard TPL Liner	ZetaLiner	Ballistic Liner Upgrade	ZetaLiner + Combo Earcup	Standard Earcup (Dimple)	Combo Earcup (Dimple)
Top	0.14	0.15	0.11			
Back	0.21	0.17	0.30			
Front	1.30	0.36	1.20			
Right Side	0.30	0.24	0.34	0.28		
Left Side	0.34	0.19	0.41	0.23	0.71	0.16

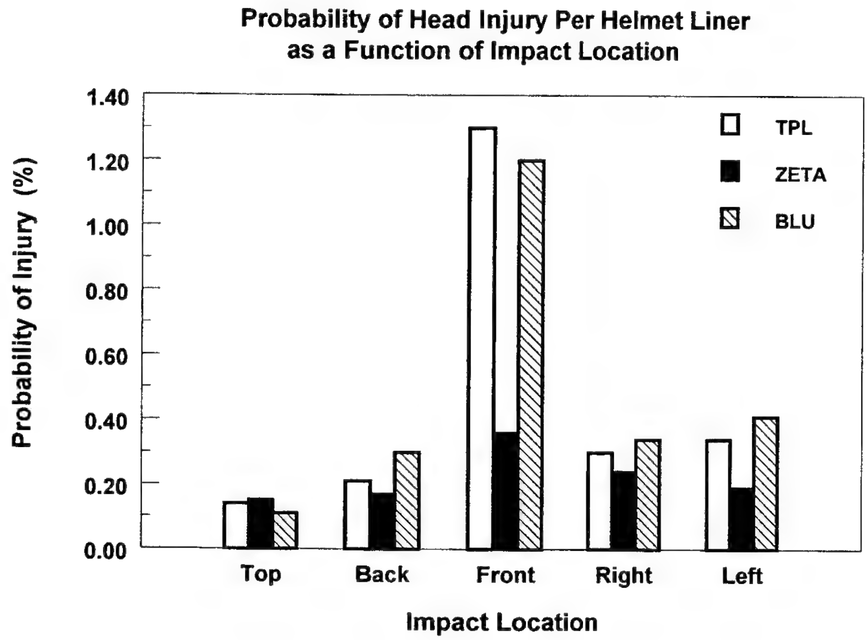

Figure 7. % Probability of Head Injury Values (AIS>4) per Liner Configuration

The HIC values and the probability of injury values both show the same relationships between the standard liner and earcup, and the proposed upgrades. Similar to the acceleration data, the ZetaLiner provides the best protection over the other liner selections with its ability to minimize the probability of head injury. This is most notable from the impacts to the front of the helmet, where it reduced the probability of head injury by a factor greater than 3. The Combo Earcup reduced the probability of head injury by a factor greater than 4 when compared to the probability with the standard earcup during side impact over the dimple of the helmet.

CONCLUSIONS

A series of helmet impact tests were conducted using the vertical Helmet Drop Tower (HDT) facility to evaluate different hard and soft liner combinations. The tests exposed an HGU-55/P helmet to impacts against a hemispherical anvil as outlined in Military Standard MIL-H-87174. The helmet impact data were used to evaluate the effectiveness of the Oregon Aero ZetaLiner in reducing head acceleration and head injury potential as compared to the standard TPL liner. Helmet impact tests were also conducted with the HGU-55/P helmet fitted with the Oregon Aero

Ballistic Liner Upgrade (BLU). The BLU replaced the rigid foam liner in the standard helmet shell. These additional tests, conducted with a TPL liner, were used to compare the impact attenuation performance of the BLU against the standard rigid foam liner.

All helmet test conditions passed the MIL-H-87174 standard at all five impact locations. The ZetaLiner showed improvement over the TPL in terms of peak head acceleration response. In general, the BLU did not perform as well as the TPL because it produced, on average, higher peak head accelerations. The Combo Earcups showed a substantial improvement in head acceleration from a side impact over the helmet dimple, when compared to the head acceleration measured with the standard hard-shell earcup.

The evaluation of the HIC and probability of injury also showed the same comparison trends as the acceleration data. Most notably, the ZetaLiner reduced the probability of head injury by a factor of 3 when compared to the values for the standard HGU-55/P TPL and the BLU. In addition, the Combo Earcup reduced the probability of head injury by a factor of 4 when compared to the value for the standard HGU-55/P earcup.

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APPENDIX A.

Test Configuration and Data Acquisition for the Helmet Drop Tower

TEST CONFIGURATION AND DATA ACQUISITION SYSTEM

FOR THE

HELMET IMPACT with ZETALINER TEST PROGRAM

(ZetaLiner Study)

Prepared under
Contract F3301-96-DJ001

November 1999

DynCorp
Human Effectiveness Division
Building 824, Area B
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INTRODUCTION

The DynCorp Human Effectiveness Division prepared this report for the Air Force Research Laboratory, Human Effectiveness Directorate, Biodynamics and Acceleration Branch (AFRL/HEPA) under Air Force Contract F3301-96-DJ001. It describes the test facility, test configurations, data acquisition, and the instrumentation procedures that were used in the Helmet Impact with ZetaLiner Test Program. Twenty-six tests were conducted between 25 Aug and 2 Sep 1999 on the Helmet Drop Tower facility.

1. TEST FACILITY

The AFRL/HEPA Helmet Drop Tower facility, Figure 1, is a 19-foot vertical tower.

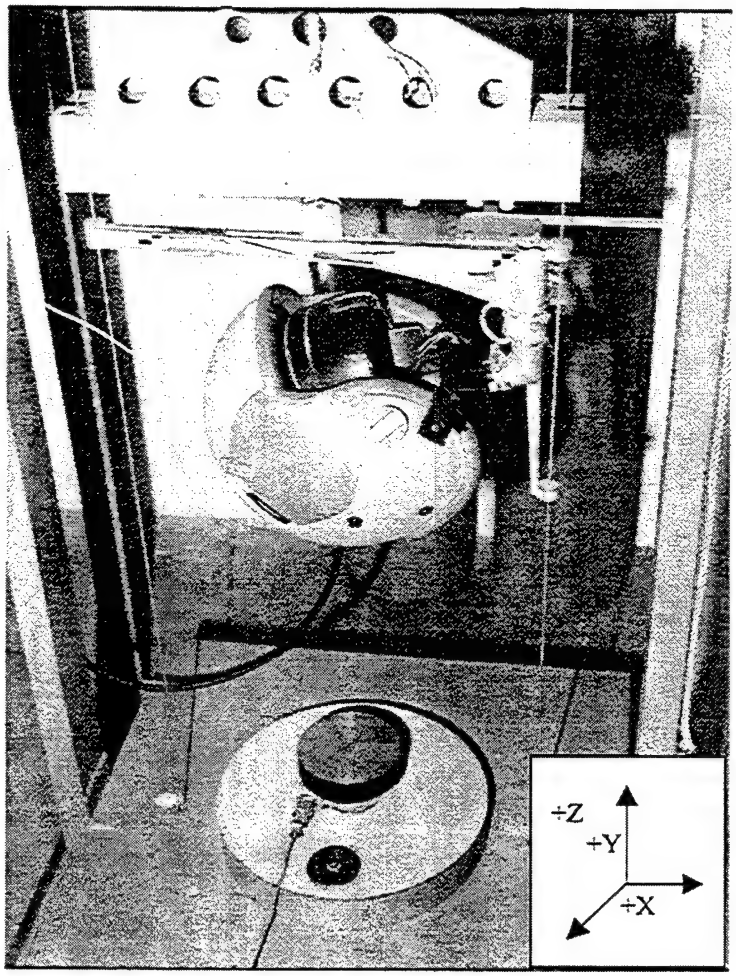

FIGURE A - 1: HELMET DROP TOWER FACILITY

A-3

It has a 300-pound reaction mass at the base and a wire-guided free fall carriage. The carriage is equipped with a gimbaled, low resonance magnesium alloy headform, Figure A - 2. The headform can be rotated to any position and then locked in order to simulate impacts on any portion of the helmet or any desired head axis. Subject helmets are normally dropped on an anvil at the base, which can be fitted with various impact surfaces. Either or both the headform and the anvil can be instrumented to satisfy test requirements. The maximum drop height is sixteen feet. For impact control, the carriage with the test helmet is weighed, and the required drop height is computed from the desired impact energy or impact velocity.

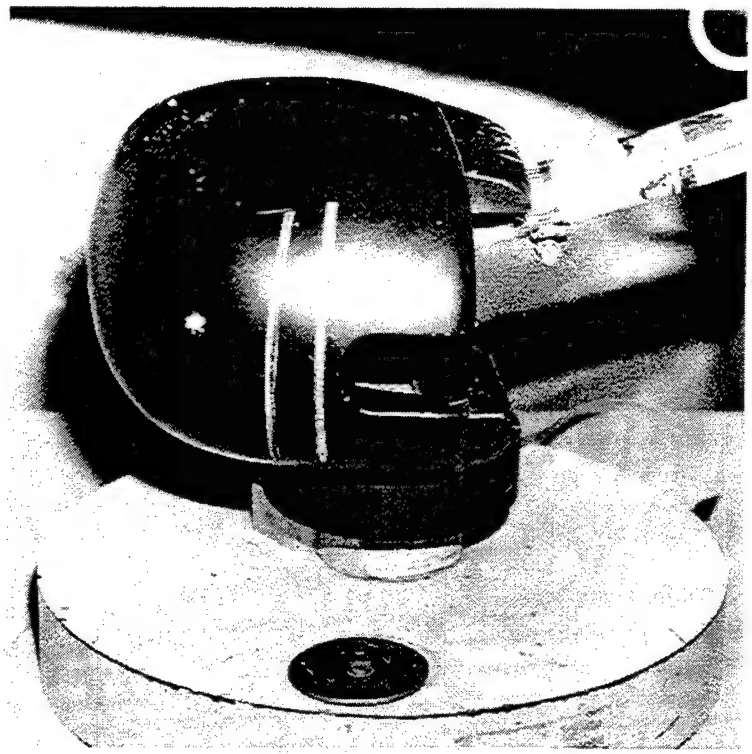

FIGURE A - 2: MAGNESIUM ALLOY HEADFORM

2. TEST SUBJECT

This was a qualification study to determine if the proposed ZetaLiner could comply with the impact attenuation specifications for aircrew helmets. The ZetaLiner is made from rate sensitive foam, and is shown in Figure A-3. A standard USAF HGU-55/P helmet was used on the instrumented headform in three different configurations. The test configurations were: the current standard configuration with a TPL liner and rigid foam insert; the ZetaLiner with the rigid foam insert; and the ZetaLiner with the Ballistic Liner Upgrade (BLU). The BLU is a planned replacement for the rigid foam insert. The BLU is shown in figure A-4.

FIGURE A - 3: ZETALINER WITH HGU-55/P

A-5

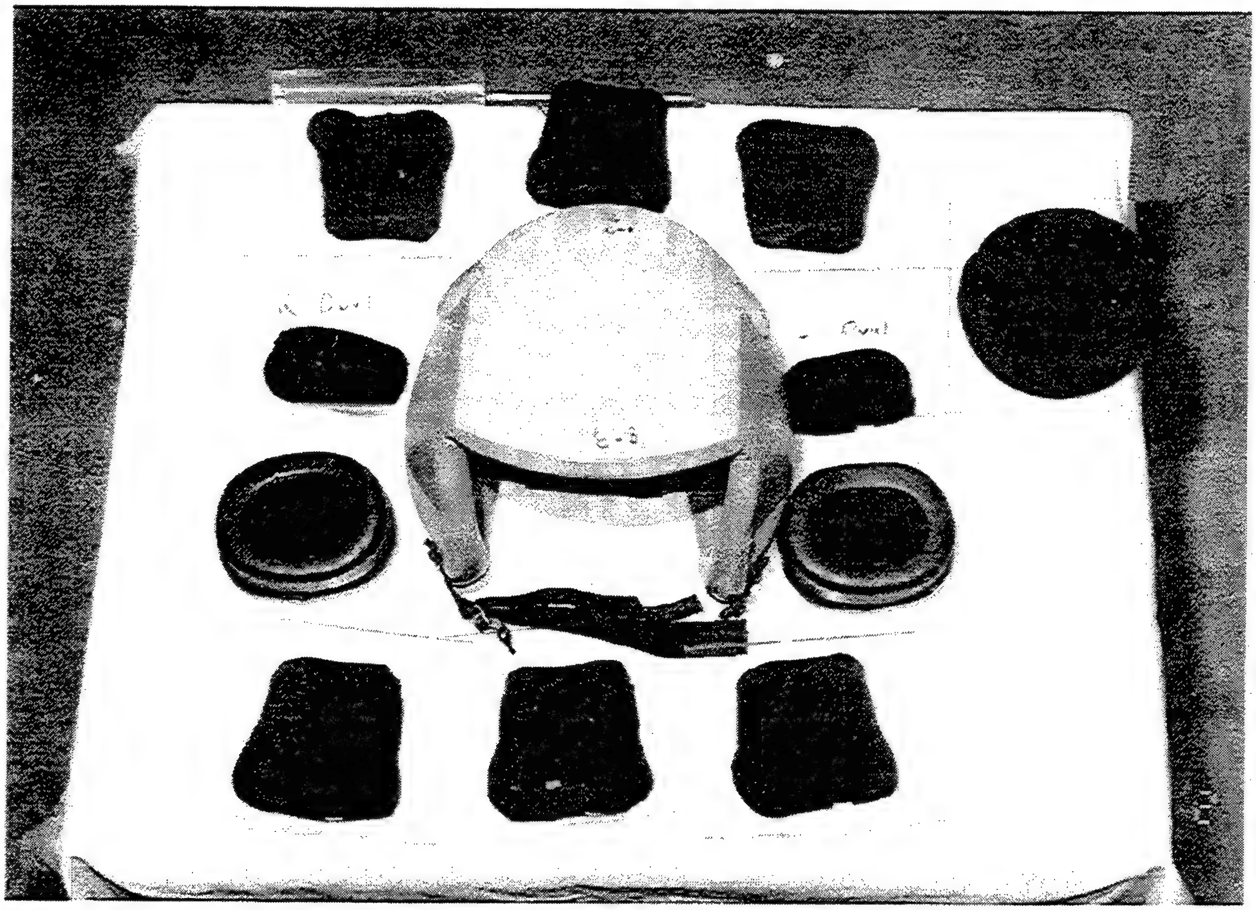

FIGURE A - 4: BALLISTIC LINER UPGRADE FOR HGU-55/P

A-6

3. TEST CONFIGURATIONS

The cell names for the various test conditions are outlined below:

	Helmet Impact Location				
CONFIGURATION	**TOP**	**BACK**	**FRONT**	**RIGHT**	**LEFT**
Standard TPL Liner	A1	A2	A3	A4	A5
ZetaLiner	B1	B2	B3	B4	B5
Ballistic Liner Upgrade	C1	C2	C3	C4	C5
ZetaLiner w/ Combo Earcup				D4	D5
ZetaLiner w/ Standard Earcup (Impact over dimple)					E5
ZetaLiner w/ Combo Earcup (Impact over dimple)					F5

TABLE A - 1: TEST MATRIX

4. INSTRUMENTATION

For this helmet impact study, one headform accelerometer and one load cell (located between the impact anvil and reaction mass) were used. Specific sensor information is given in Table A - 2. The transducers were chosen to provide the optimum resolution over the expected test range. Full scale data ranges were chosen to cover the expected peak values plus 50% to assure complete signal capture. The transducer bridge was balanced for optimum output at the start of the program. The accelerometer was compensated for the effect of gravity in software by adding the component of a positive one G vector in line with the force of gravity.

The coordinate reference system for this study is shown in Figure A-1. It is a right-handed system with no origin defined because only vector directions were required. The Z-axis is positive upward along the guide wires. The X-axis is perpendicular to the plane of the guide wires and is positive coming out of the page in Figure A - 1. The Y-axis is orthogonal to X and Z, and is positive to the right in Figure A -1.

The linear accelerometer was wired to provide a positive output voltage when acceleration was experienced in the +Z direction. The load cell was wired to provide a positive output voltage when it exerted a positive Z direction force on the test specimen.

4.1 Calibration

Calibrations were performed before and after testing to confirm the accuracy and functional characteristics of the transducers. Pre-program and post-program calibrations are given in Table A-1. The Precision Measurement Equipment Laboratories (PMEL) at Wright-Patterson Air Force Base calibrated the Strainsert load cell. PMEL calibrates all load cells on a periodic basis and provides current sensitivity and linearity data.

DynCorp calibrated the accelerometer by using the comparison method (Ensor, 1970). A laboratory standard accelerometer, calibrated on a yearly basis by Endevco with standards traceable to the National Bureau of Standards, and a test accelerometer were mounted on a shaker table. The frequency response and phase shift of the test accelerometer were determined by driving the shaker table with a random noise generator and analyzing the outputs of the accelerometers with an MS-DOS PC computer using Fourier analysis. The natural frequency and the damping factor of the test accelerometer were determined, recorded and compared to previous calibration data for that test accelerometer. Sensitivities were calculated at 40 G and 100 Hertz. The sensitivity of the test accelerometer was determined by comparing its output to the output of the standard accelerometer.

5. DATA ACQUISITION

The Master Instrumentation Control Unit in the Instrumentation Station controls data acquisition. Using a comparator, a test was initiated when the countdown clock reached zero. The comparator was set to start data collection at a pre-selected time. All data was collected at 10,000 samples per second and filtered at 120 Hz cutoff frequency using an 8-pole Butterworth filter.

A reference mark pulse was generated to mark the electronic data at a pre-selected time after test initiation, and place it close to the time of impact. The reference mark time was used as the start time for processing of the electronic data.

5.1 Model 5600 Portable Data Acquisition System

The Model 5600A Portable Data Acquisition System (DAS), manufactured by Pacific Instruments, was used for this test program. The Model 5600A DAS is a ruggedized, DC powered, fully programmable signal conditioning and recording system for transducers and events. The Model 5600A DAS is shown in Figure A-5.

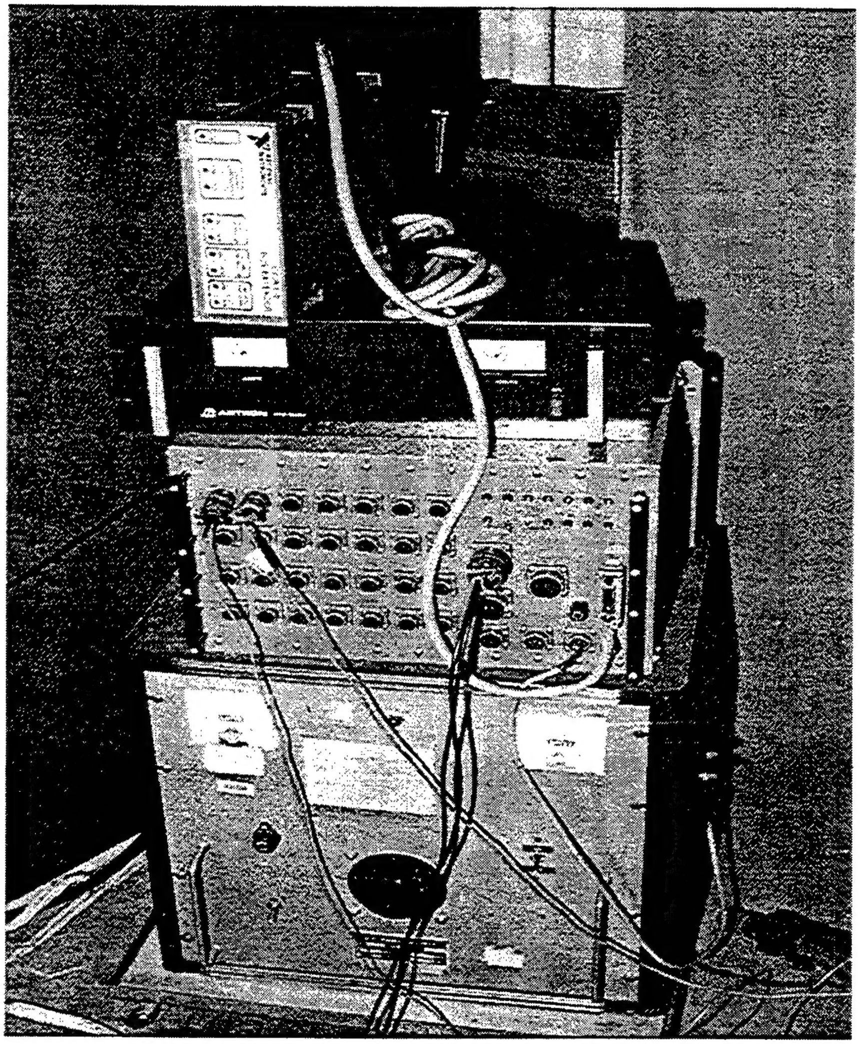

FIGURE A - 5: PACIFIC INSTRUMENTS MODEL 5600A

The single unit can accommodate up to 28 transducer channels and 32 events. The signal conditioning accepts a variety of transducers including full and partial bridges, voltage, and piezoresistive. Transducer signals are amplified, filtered, digitized and recorded in onboard solid state memory. The data acquisition system is controlled through an IEEE-488.1 interface using the GPIB instruction language.

The DynCorp program 'TDR5600' on the PC handles the interface with the Model 5600A DAS. It includes options to compute and store zero reference voltage values; collect and store a binary zero reference data file; compute and display preload values; and collect and store binary test data. The program communicates over the GPIB interface.

Test data could be reviewed after it was converted to digital format using the "quick look" SCAN_EME routine. SCAN_EME produced a plot of the data stored for each channel as a function of time. The routine determined the minimum and maximum values of each data plot. It also calculated the rise time, pulse duration, and carriage acceleration, and created a disk file containing significant test parameters.

5.2 High Speed Video System

A Kodak Ektapro 1000 video system was also used to provide onboard coverage of each test. This video recorder and display unit is capable of recording high-speed motion up to a rate of 1000 frames per second. Immediate replay of the impact is possible in real time or in slow motion. For this study, all tests were recorded at 500 frames per second. Figure A - 6 shows the camera position in the overall test setup.

6. PROCESSING PROGRAMS

The only processing provided for this study was the DynCorp 'Quick Look' report. The report contains time histories of each channel in engineering units, a tabular summary of results, and a plot of each time history.

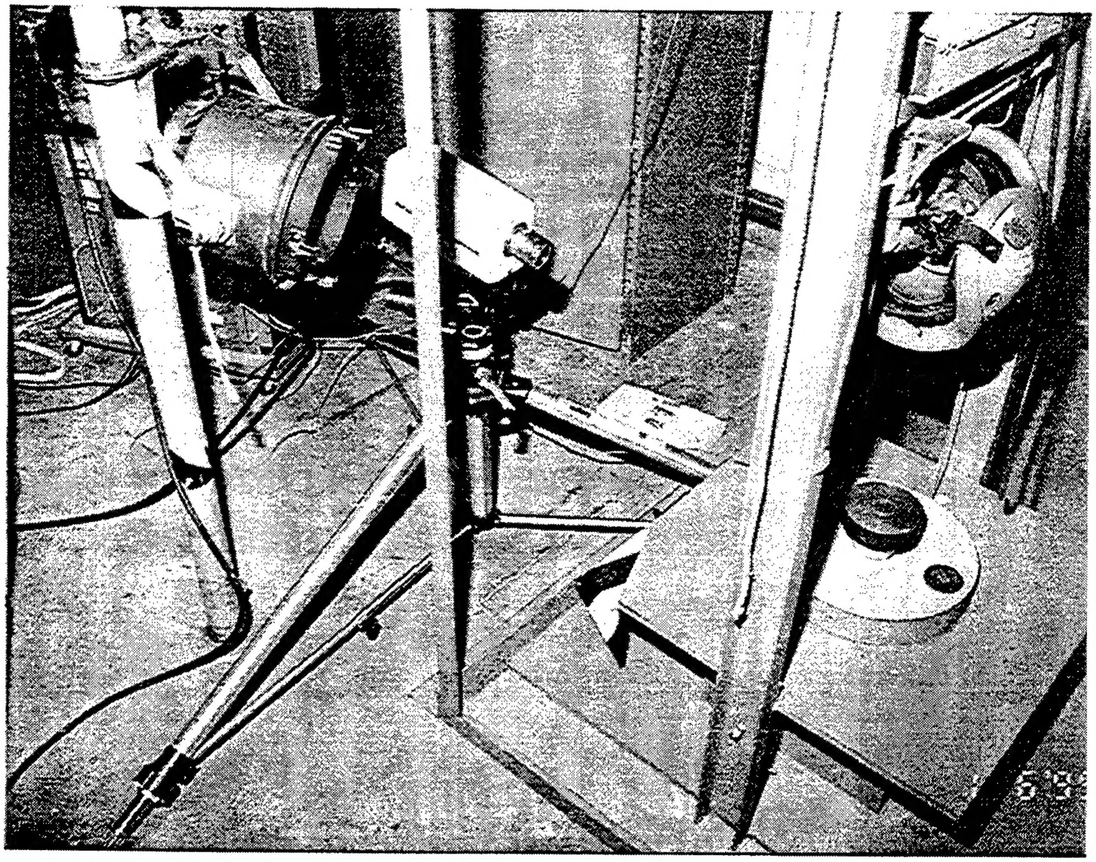

FIGURE A - 6: HIGH SPEED CAMERA

DynCorp Program Setup and Calibration Log

PROGRAM: HELMET IMPACT WITH ZETALINER	TEST DATES: 25 AUG 1999 - 2 SEPT 1999
STUDY NUMBER : 199905	TEST NUMBERS: 9942 - 9967
FACILITY: HELMET DROP TOWER	SAMPLE RATE: 1K
	FILTER FREQUENCY: 120 Hz
DATA COLLECTION SYSTEM: PACIFIC INSTRUMENT	TRANSDUCER RANGE (VOLTS): +/- 10

DATA CHANNEL	DATA POINT	TRANSDUCER MFG. & MODEL	SERIAL NUMBER	PRE-CAL		POST-CAL		% Δ	EXC. VOL.	AMP GAIN	FULL SCALE	NOTES
				DATE	SENS	DATE	SENS					
0	HELMET DROP ACCELl (G)	ENTRAN EGA-125F-500	14A5-918-A1	29-Jan-99	.4157 mv/g	13-Sep-99	.4185 mv/g	.7	10 V	50	481.12G	
1	HELMETt DROP FORCE (LB)	STRAINSERT FL5U2SPKT	Q-3882-1	12-Apr-99	-4.04 uv/lb	N/A			10 V	500	4950.5	USE NEGATIVE SENSITIVITY
28	EVENT/ T=0								0	1		Bit 0 is Event Bit 1 is T=0

TABLE A - 2: INSTRUMENTATION LOG